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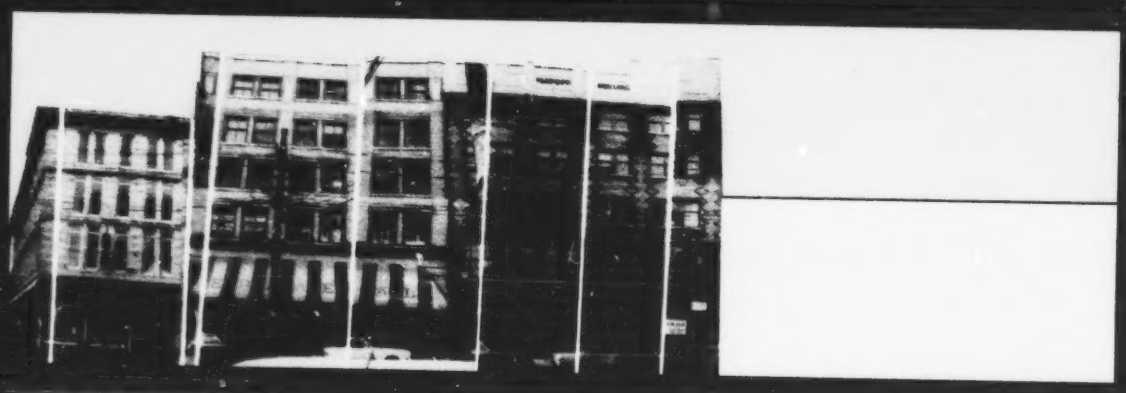

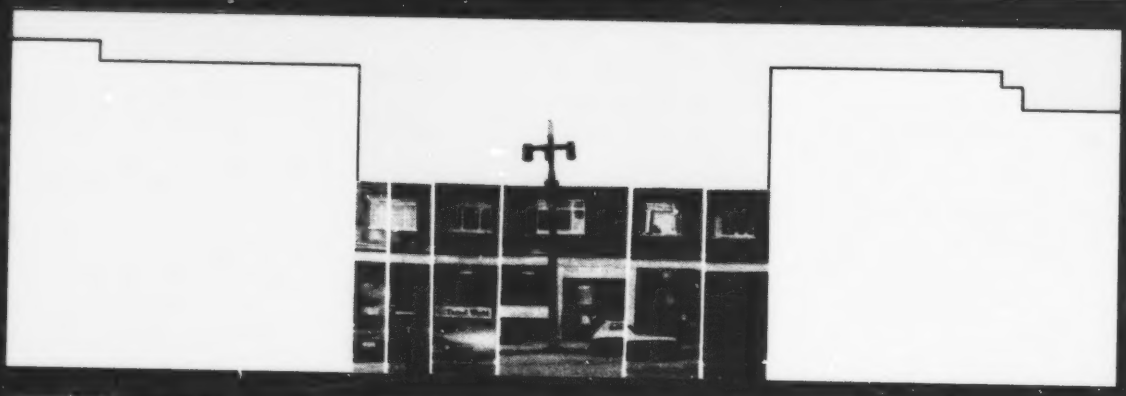

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Technical Paper Series 8

Seismic Building Upgrading

For Vancouver's Gastown

Prepared under the
British Columbia Heritage Trust
1984 Student Employment Program

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Brenda Wong
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We would like to thank our sponsor, Gastown Historical Society for its support and the architects and engineers who assisted us on this project.

Cover

Block 300, Water Street, taken in 1969, supplied by Jan Paul Shason, Gastown Printers.

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Titles already published in this series:

Bradshaw, J., ***Heritage Conservation in British Columbia: A Selected Bibliography,*** 1979.

Collier, R., ***Guideline for Restoring Brick Masonry,*** 1981.

Patterson, R.M., ***Manual for the Preparation of "As Found" Drawings,*** 1982.

Collier, R., ***Guidelines for Storefronts of Heritage Buildings,*** 1982.

Harper, D., ***Trees and Towns,*** 1983.

Cassidy, M., ***Local History in British Columbia,*** 1983.

Sussman, G., ***Fire Prevention in Heritage Buildings,*** 1983.

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Foreword

Since its inception in 1977, the British Columbia Heritage Trust has been developing new ways to "support, encourage and facilitate the conservation, maintenance and restoration of heritage property in the Province." One such way is the ***Technical Paper Series.***

Although a great deal of general information on heritage subjects is already available, there has been a growing request for concise treatment of specialized subjects within the British Columbia context. Themes are therefore drawn from the fields of history, archaeology, architecture and preservation technology. The British Columbia Heritage Trust invites suggestions for further studies in this series.

Introduction

The intention of this project is to provide a structural analysis of existing heritage buildings in Vancouver's Gastown. This is a prerequisite for a consolidated engineering design to upgrade the buildings to the existing seismic requirements established by the City of Vancouver. This study is based on the assumption that it would be more economical to upgrade these buildings as a group rather than on an individual basis. This approach was suggested by the City of Vancouver as a potential significant money-saving technique in meeting the seismic code requirements for these heritage buildings.

From the research conducted over a three-month period, several alternate methods of seismic upgrading are proposed for a group of buildings on a test block.

The criteria for selecting a test block were representative building type, available documentation and accessibility to gathering further information for the purpose of this study.

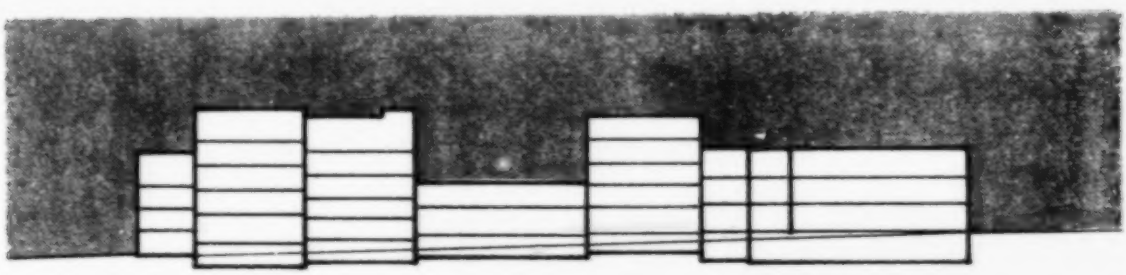
The block of buildings chosen for the analysis is the 300 block on the south side of Water Street. These eight buildings are relatively typical of the Gastown area as they display the kind of construction methods and materials used in this historic site at the turn of the century. Generally, the walls are constructed of brick and/or stone unreinforced masonry with interior vertical load-bearing heavy timber posts and beams. Cast iron columns are used in two of the buildings on the first level as a supporting framework for the storeys above. The block includes a triangular 'flatiron' end which exemplifies a number of blocks in Gastown.

300 Block Water Street

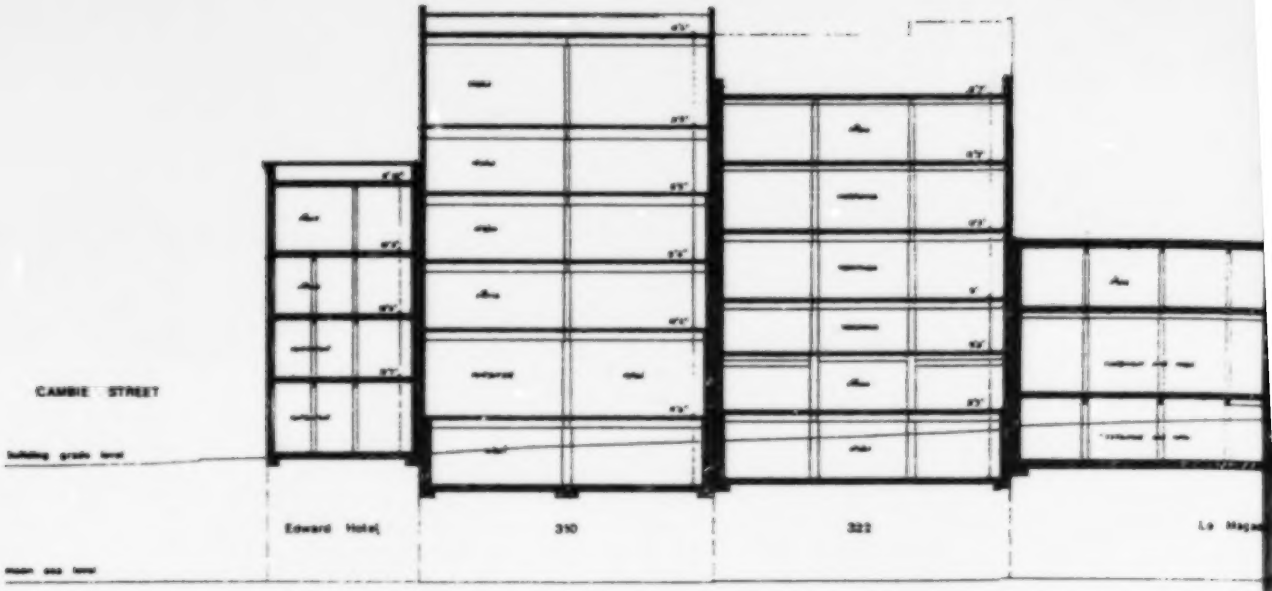
1. Preliminary Investigation

An investigation of each building was conducted to document its architectural merit and to determine its present structural condition. Without the use of special equipment many important elements of the structural system were not visible. It was therefore necessary to make some assumptions about the buildings with the assistance of local architects and engineers who are familiar with these or similar buildings in the Gastown area. These assumptions include wall thicknesses and the composition of wall and floor structures.

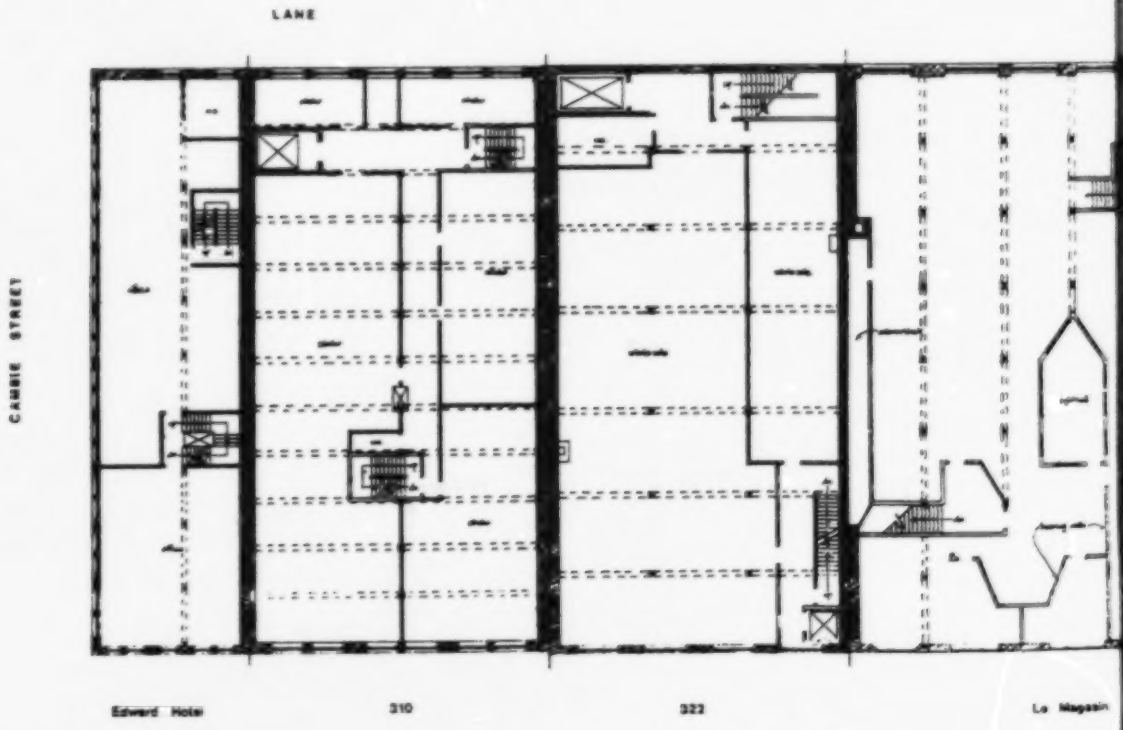
With a few exceptions, these buildings have been fairly well maintained and are basically sound structures. Most of them have been renovated over the past ten years to accommodate new uses and tenants. In general, any architectural changes to the facades have been sympathetic to and consistent with the styles and materials of other Gastown buildings. The strength and value of these buildings as a significant historical group and in the unique aesthetic feature which some of them possess is a strong consideration in formulating qualitative goals for seismic upgrading.



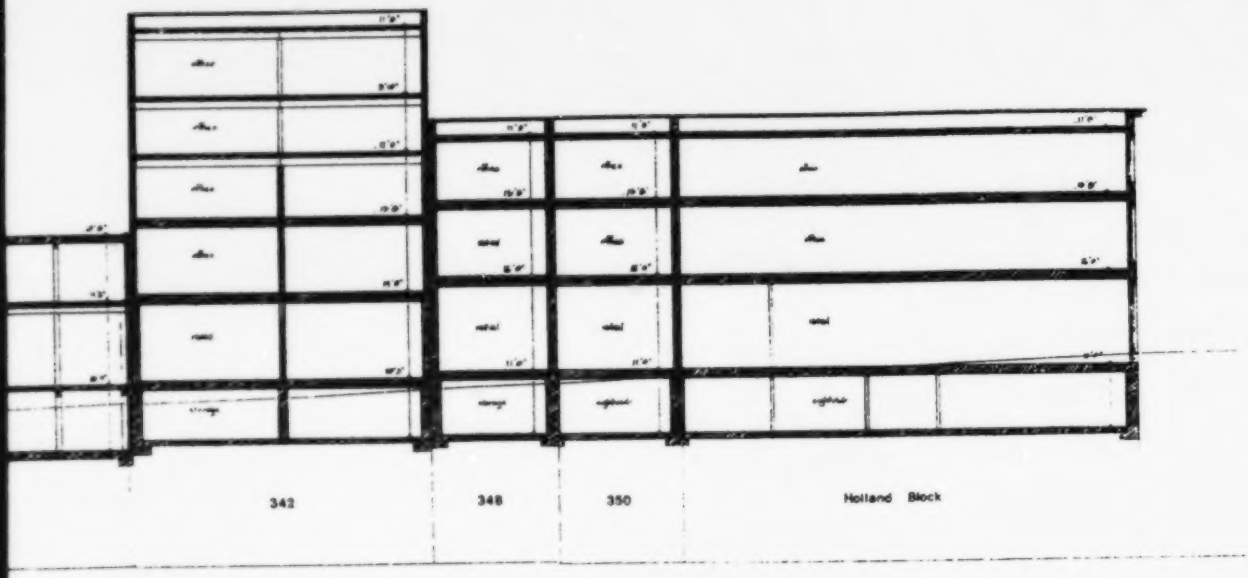
Elevation: 300 Block Water Street

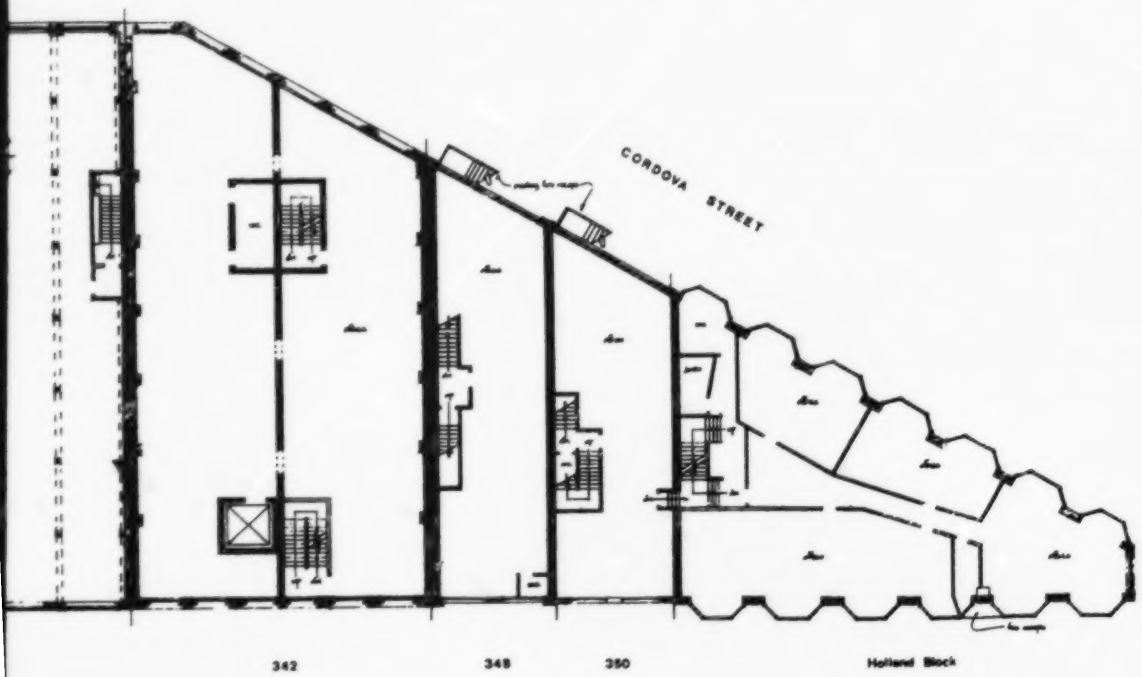


Lateral Cross-section

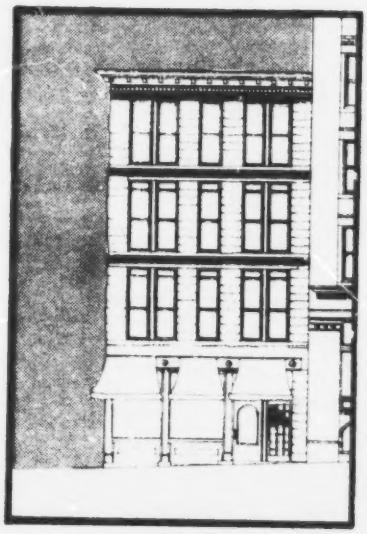


Typical Floor Plan: Existing


342
348
350
Holland Block


CORDOVA STREET
342
348
350
Holland Block

1.1 Present Condition of the Buildings



Edward Hotel
300 Water Street

In 1906, the Edward Hotel was constructed on this site to replace the Regina Hotel, the only building to survive the great fire of 1886. The building has changed little over the years and is characterized by simple perpendicular lines and rusticated stone cladding. Carved horizontal floral bands wrap around the building and, unlike many old buildings in Gastown, the cornice is still intact.

Edward Hotel: 300 Water Street

Dimensions: 25 ft. x 100 ft. Height: 46 ft.

Floor System: The floor system is probably constructed of 2x10 in. joists, finished with 5½ in. tongue and groove flooring and ¾ in. drywall (this should be checked and verified). The connection of the floor system to transfer the lateral loads to the walls is poor.

Walls: From the available information and observations made, the west wall is probably concrete with an approximate thickness of 8 in. (this should be checked and verified). The south wall (facing the lane) is constructed of unreinforced masonry (thickness = 16 in.) and has few openings. The structural system of the east and north walls (facing Cambie and Water Streets respectively) consists of cast iron columns on the ground level (9 in. diameter), two stacked I beams spanning these columns (15 in. depth), and unreinforced masonry walls (thickness = 16 in.) above punctuated with many windows.

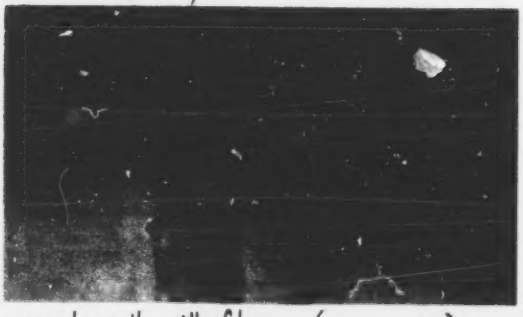
Timber Framing: The framing generally consists of one or two rows of 6x6 in. posts and beams on each floor, with some discontinuities. The spacing of posts is approximately 10 ft. o.c. along the north south axis, with the beams also spanning across the columns in the same direction. The connections have no lateral stability.

· column / beam connection, 2nd floor only

· column / beam connection, 3rd floor

· column / beam connection, 2nd floor only

· slipped connection, 3rd floor

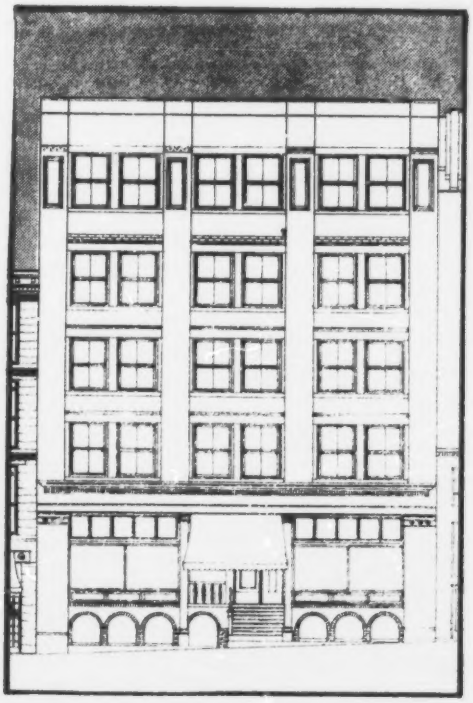


· west wall, 4th floor (concrete)

· slipped connection, 3rd floor

· typical column / beam connection, 3rd and 4th floors

· knee braced connection, 3rd floor



310 Water Street

This five storey building typifies the use of heavy timber posts and beams as interior load bearing elements in warehouse construction in Gastown. The linear rhythm of the slightly recessed windows is interrupted by the addition of brick arches at the ground level. The cornice has been removed and replaced by a low parapet wall.

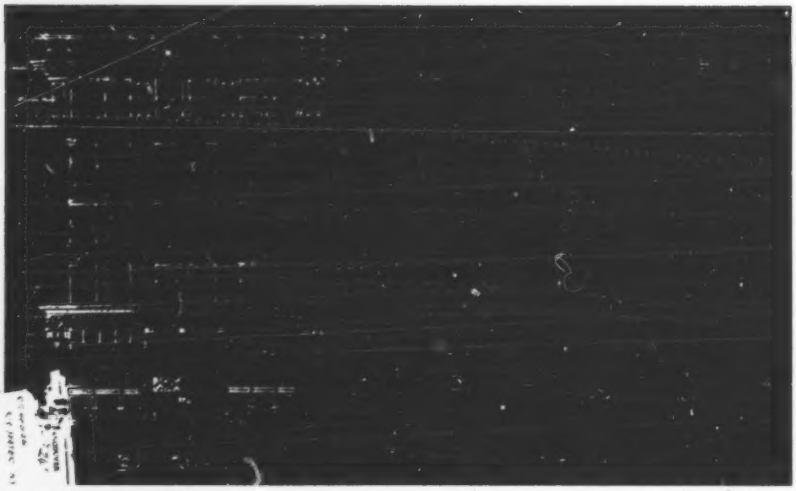
310 Water Street

Dimensions: 50 ft. x 100 ft. Height: 80 ft.

Floor System: the 6 in. floor consists of two layers of tongue and groove planks 2x8 in. with a tongue and groove finish on heavy timber beams. The connection of the floor system to transfer the lateral loads to the walls is poor.

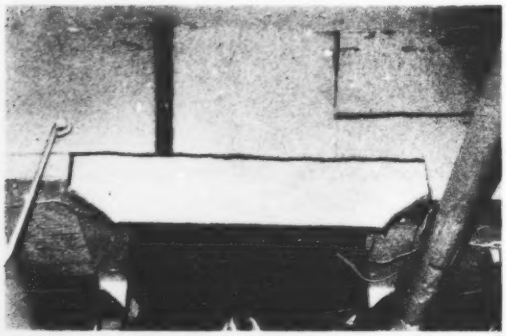
Walls: From the observations made, the east wall (adjacent to the Edward Hotel) is probably a concrete wall with an approximate thickness of 8 in. (this should be checked and verified). The other walls are constructed of unreinforced masonry. The west wall varies in thickness from 24 in. at the foundation level to 13 in. at the top storey. The north and south walls are punctuated with many windows.

Timber Framing: The framing consists of heavy timber columns varying in size from 16x18 in. on the ground floor to 8x8 in. on the fifth floor, at 8 ft. o.c. along the north-south axis. Timber beams span the columns in the east-west direction. The connections have no moment carrying capacity and many of the timber sections are cracked.

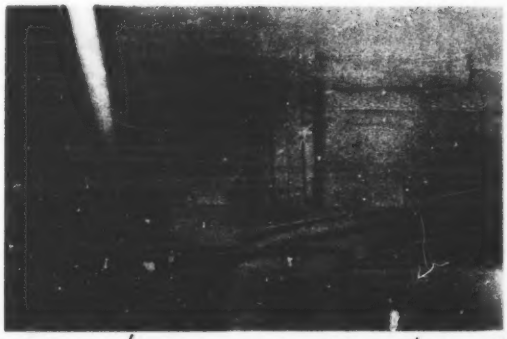


Vancouver City Hall micro-fiche files.

· 1911 elevation shows original cornice on building



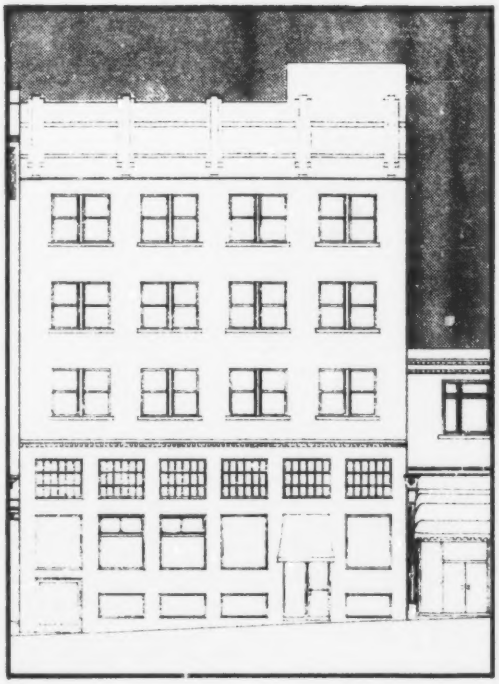
· column / beam connection, typical



· column / beam connection, typical

· typical wall / beam connection, all floors

· east wall, 3rd floor (concrete?)



322 Water Street

The simple facade of this old warehouse building reveals an addition of three storeys on top of the original structure. The contrasting pattern of dark and light brick provides some visual interest in an otherwise flat and unadorned building face.

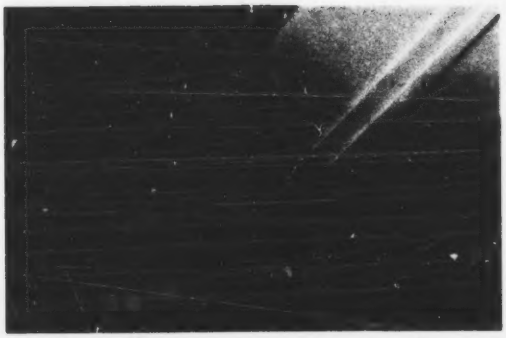
322 Water Street

Dimensions: 49 ft. x 100 ft. Height: 65 ft.

Floor System: The floor structure consists of 6 in. laminated wood with lath/plaster over. The connection of the floor system to transfer the lateral loads to the walls is poor.

Walls: The walls are constructed of unreinforced masonry. The thickness of the foundation wall is approximately 20 in., with the other walls about 16 in. thick. The north and south walls have many openings.

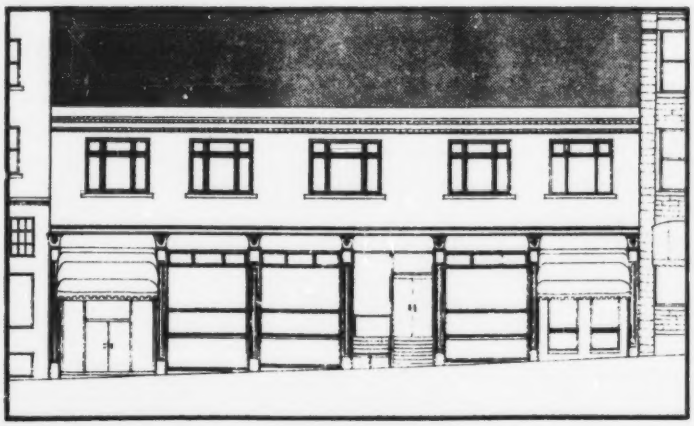
Timber Framing: The framing consists of heavy timber sections varying in size from 18x18 in. on the basement and main floor to 12x12 in. on the fifth floor. There are two rows of columns along the north-south axis varying from 13 ft. to 17 ft. o.c., with beams spanning in the east-west direction. The main floor has steel I beams (S310x47) spanning the columns in the centre. Cracks in the timber sections have been observed.



• column/beam connection, typical

• cracked column

• column/beams connection, main floor



Le Magasin
332 Water Street

Le Magasin was recently renovated to accommodate shops and a restaurant on the basement and main level, and offices on the top storey. The structural and architectural changes made on the lower portion of the building façade provide rich colour and texture to the dark brick masonry above

Le Magasin: 332 Water Street

Dimensions: 75 ft. x 100 ft. Height: 35 ft.

Floor System: The floor system consists of 2x6 in. joists at 16 in. o.c. on 2x4 in. laminated wood, on heavy timber beams. The connection of the floor system to transfer the lateral loads to the walls is poor.

Walls: The east wall appears to be concrete (this should be checked and verified). The west wall belongs to the adjacent building, and is unreinforced stone masonry at the foundation level and unreinforced brick masonry at the upper floors. The walls facing Water Street and the lane are punctuated with many windows.

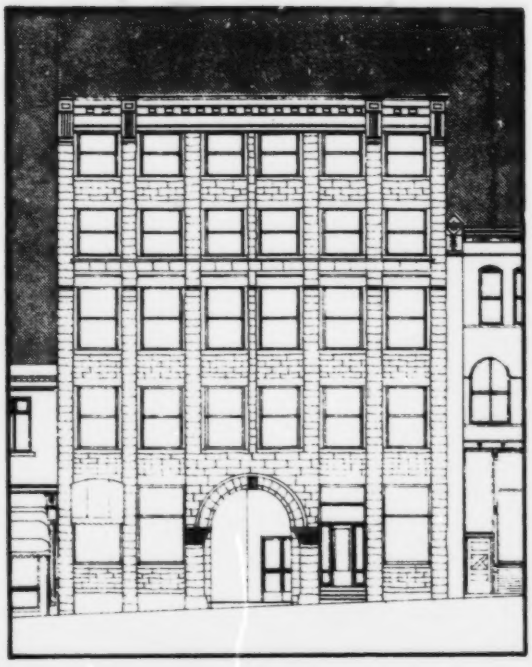
Timber Framing: The framing consists of heavy timber sections varying from 12x12 in. in the basement to 8x8 in. in the upper levels. The columns are placed in a grid at 12 ft. to 13 ft. o.c. The beams run in the north-south direction in the basement and roof level, and east-west direction in the main level. There are some load-bearing walls where column discontinuities occur.

· knee braced connection, basement

· column/beam connection, basement

· column/beam connection, typical

· beam/beam connection, typical



342 Water Street

The rusticated stonework and pier and spandrel motif of this building creates texture and rhythm to the formal design. The carved capitals and keystone head are attractive details in the arched doorway. The top two storeys were added in 1911, and the entire building was restored in 1970 for offices and retail space.

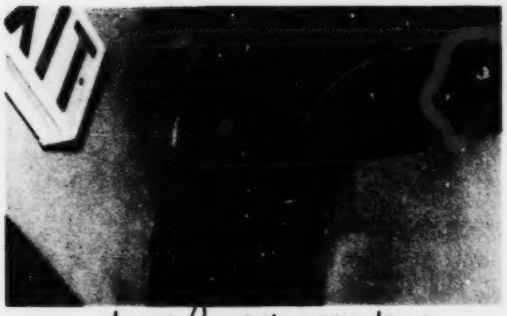
342 Water Street

Dimensions: 50 ft. x 100 ft. varying to 76 ft. on the west side Height: 72 ft.

Floor System: There are two different floor systems in this building. On the ground, second and third floors there are 3x15 in. joists at 16 in. o.c., with two layers of shiplap (thickness = 1 in.) and 1½ in. concrete topping on top of the joists. On the fourth and fifth floors there is a 2x6 in. laminated wood floor system which spans across heavy timber beams. The connection of the floor system to transfer the lateral loads to the walls and reinforced masonry shafts is good.

Walls: All the walls are constructed of unreinforced masonry. The east and west walls vary in thickness from 24 in. in the basement level to 12 in. on the top storey. The end walls are punctuated with openings. There is an unreinforced masonry wall bisecting the building along the north-south axis, from the basement level up to and including the third floor. Timber framing replaces load-bearing wall on the fourth and fifth floors with sections of varying size.

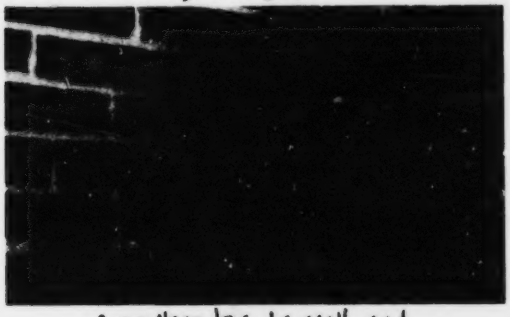
Reinforced Masonry Shafts: There are two reinforced masonry shafts well connected to the floor system at each floor level.



· column / beam connection,
4th and 5th floors

· column / beam connection,
4th floor

· beam / pier connection,
3rd floor



· centre brick wall and
foundation wall

348 and 350 Water St.

The structural system and architectural treatment of these two buildings are very similar. Not only are the buildings of the same height, but the size and shape of the arched windows are repeated from one to the other. Their design displays a style that adapts Italian architectural sources in a manner that is characteristically Victorian. Both buildings (as well as the buildings on either side of them) have entrances on Cordova Street.

348 and 350 Water Street

Dimensions: 348 Water Street: 21 ft. x 76 ft. varying to 66 ft. Height: 54 ft.
350 Water Street: 20 ft. x 66 ft. varying to 53 ft. Height: 54 ft.

Floor System: The ground floor has 2x14 in. joists at 16 in. o.c., and the second and third floors have 2x12 in. joists at 16 in. o.c. The floor system is unable to transfer the lateral loads to the walls.

Walls and Vertical Load-bearing Elements: It is assured that these two buildings share a party wall, and that a party wall is also shared by the Holland Block (west end of the block). All the walls are unreinforced masonry and vary from 16 in. to 12 in. in thickness. Cast iron columns on the ground floor support the masonry above, on the north and south walls.

Holland Block
364 Water Street

Formerly the Queens Hotel, the Holland Block is a distinctive building in Gastown with its recurrent bay windows and tapered flat iron form. Built in 1891, it is the oldest building on the block. The brick piers between each bay are clad in rusticated stone on the ground floor, adding to the variety of materials used to construct the building.

Holland Block: 364 Water Street

Dimensions: 78 ft. x 66 ft. varying to 9½ ft.
Height: 54 ft.

Floor System: The ground floor has 2x14 in. joists at 16 in. o.c., and the second and third floors have 2x12 in. joists at 16 in. o.c. The floor system is unable to transfer the lateral loads to the walls.

Walls and Vertical Load-bearing Elements: The party wall which is shared by the adjacent building is unreinforced brick masonry. The masonry piers of the south and north walls bear on cast iron columns on the ground level. As well, the ground floor and basement (the floor area of the basement is shared by the adjacent building; both buildings are owned by a single owner) have cast iron columns supporting the floor systems above, whereas the second and third floors have wood frame load-bearing walls. The structural system of the building has poor seismic resistance.

1.2. Summary

With the exception of 342 Water Street, all the buildings on the study block are unable to resist seismic forces in any direction. All masonry walls are unreinforced and the connection of the floor system to transfer lateral loads to the walls is poor. The large percentage of openings in the exterior walls also reduces the strength of the walls. There are many methods for seismic upgrading that can be applied to older buildings of this type and nature; these are discussed in chapter 3.

As a composite group, these buildings are important because of their historical significance to Vancouver's local heritage. With the exception of three of the buildings (the Edward Hotel, 342 Water Street, and the Holland Block) they are not notable pieces of architecture in themselves, but rather, when united they present a strong image of the cultural and social history of the City's past. To maintain the physical character of these buildings the architectural objectives as they relate to this study are as follows:

1.2.1. The existing brick walls, and heavy timber posts and beams should be preserved as qualitative features of the buildings. These structural elements are intrinsically valuable as they exhibit a construction method and materials that contemporary architecture cannot duplicate.

1.2.2. Materials used for structural upgrading should be compatible (or used in a compatible manner) with the existing materials of the buildings.

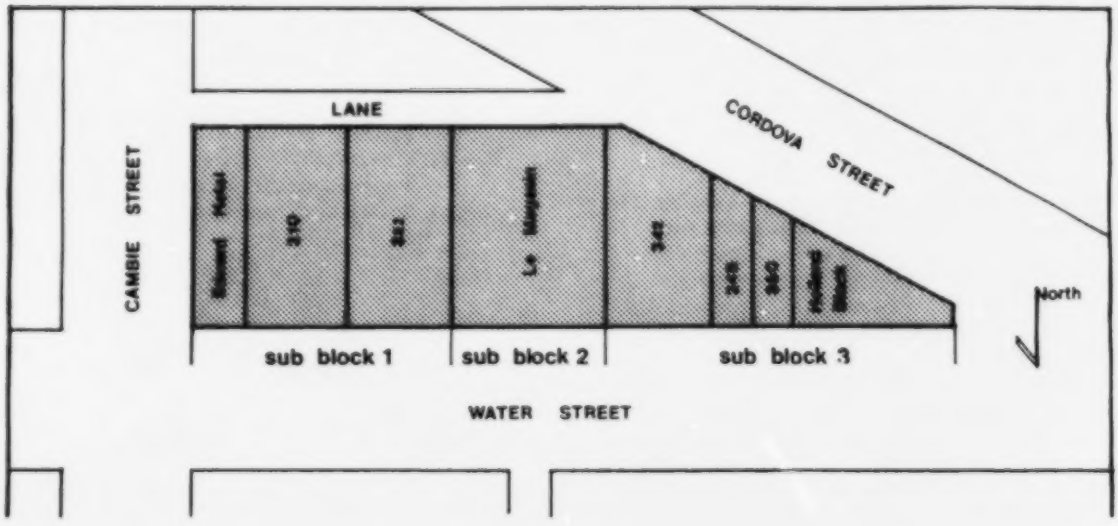
1.2.3. New structural elements added to the buildings should not interfere with the aesthetic appearance of the building facade.

1.2.4. New structural elements should not significantly alter the size and the shape of wall openings (i.e. windows).

1.2.5. Ornamental details which enhance the aesthetic and historical value of the buildings should not be removed.

1.2.6. The methods proposed for seismic upgrading should maintain or improve the interior space(s) of the buildings.

These recommendations should be considered as guidelines in selecting the appropriate methods to strengthen the buildings to resist seismic forces.



2. Advantages of a Consolidated Engineering Design Versus Individual Upgrading

Since all of the buildings within the study block are adjacent to each other, they are subject to a 'domino effect' in the event of an earthquake. Individually, every structural system responds to a ground motion in a different period. Consequently, the mode shapes of these systems do not coincide. This causes the buildings to collide together because of a ground motion induced by an earthquake in the east-west direction and their subsequent structural failure. Although the buildings may be seismically upgraded on an individual basis, this condition will still occur since each building is considered as a separate unit. The impact effect which can cause tensile stresses in the unreinforced masonry walls of adjacent buildings must still be considered, since the floor levels of these buildings are not aligned. As a result, the structural requirements are overdesigned for each building to resist this impact effect and a consolidated approach is favoured.

In a consolidated design, the walls of adjacent buldings are tied and strengthened together eliminating the failure of the walls. As a result, the buildings act as a unified group and their ability to resist seismic forces is increased. Other factors which favour a consolidated design for seismic upgrading in this situation are:

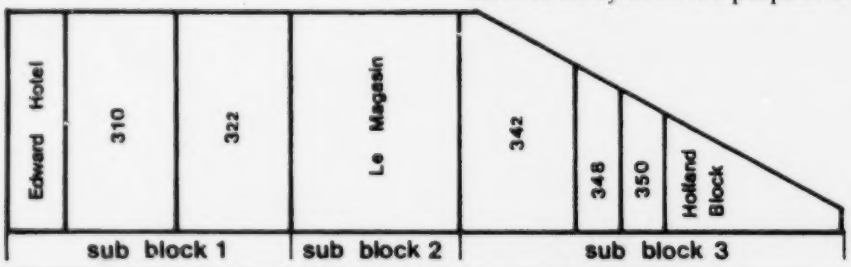
2.1. Some of the buildings share party walls and therefore should be considered as single structures.

2.2. A consolidated design approach creates structurally more redundancy which delays a possible failure.

2.3. The buildings which are located at each end of the study block (the Edward Hotel and the Holland Block) have very poor lateral load-resisting systems and eccentricity which causes torsion effects. Tying the buildings together and arranging the proper earthquake-resistant systems for this amalgamated group can relieve this eccentricity and resist the lateral loads. Some structural retrofitting must be done on each building in conjunction with this.

For the purpose of formulating a consolidated engineering design, the study block was divided into three sub blocks. This was primarily based on the location of the buildings within the block and similarities or differences in height.

Sub Block 1 consists of the three buildings at the western end of the block (the Edward Hotel, 310 and 322 Water Street), and **Sub Block 3** consists of the four buildings at the eastern end of the block (342, 348 and 350 Water Street and the Holland Block). Le Magasin, being much lower than the other buildings is considered as a separate unit (**Sub Block 2**). Since 342 Water Street is the only building within the study block that has been seismically upgraded, the condition of the building prior to upgrading is hypothetically used for analysis for the purpose of this study.



3. General Structural Recommendations for Seismic Upgrading

Building regulations or building codes adopted by local governmental agencies in North America are generally based on a model code such as the National Building Code. These codes are written for new construction using modern materials and construction techniques. They do not include provisions for the archaic materials of construction present in old buildings which are remodelled or strengthened. Thus, the Building Code does not provide guidance to the engineer nor criteria for the building official in evaluating the available strength of the building for lateral loads. Yet engineers have recognized some qualitative goals for seismic retrofit: to tie the floors to walls and adjoining walls together with added connectors and lateral load resistant elements: to create redundancy and multiple load paths; to tie the buildings together so that they act as a whole; to develop tensile capacity particularly for out-of-plane flexure in walls; and to develop ductility by keeping the masonry units together after the mortar joints have cracked.

The following information attempts to summarize several approaches to strengthen buildings that have poor seismic resistance and would not comply with current codes because of their type and nature. The buildings of this study fall into this category.

3.1 Floor-to-Wall Connections

Improving connection details to force walls and vertical structural members to move with the floor and roof diaphragms seems a low cost method which greatly increases a building's seismic resistance. Roofs have collapsed because the load-bearing walls on the opposite side of the building moved in opposite directions during an earthquake (Reference 2). Securely connecting each wall to the floor forces the walls to deflect in similar directions, thus the walls remain under the roof structure and collapse is prevented.

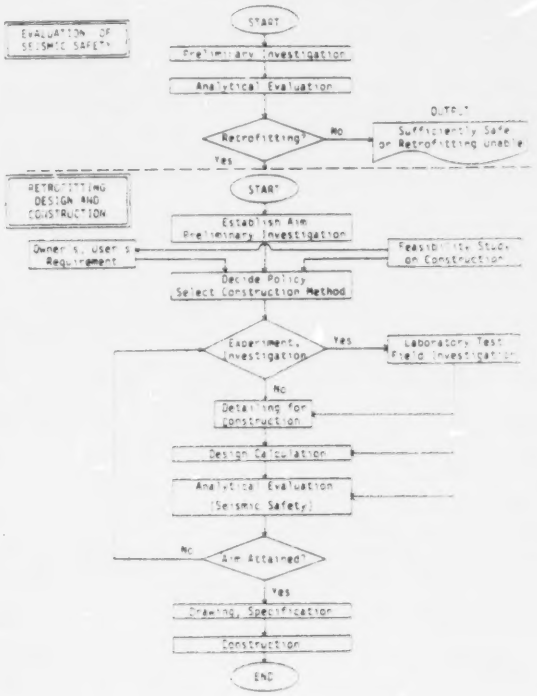


Figure 1: Flow chart of design and construction of seismic strengthening.

3.1.1. Wood Floor-to-Wall Connections: These connections are constructed as illustrated in **Figures 2, 3** (Reference 1).

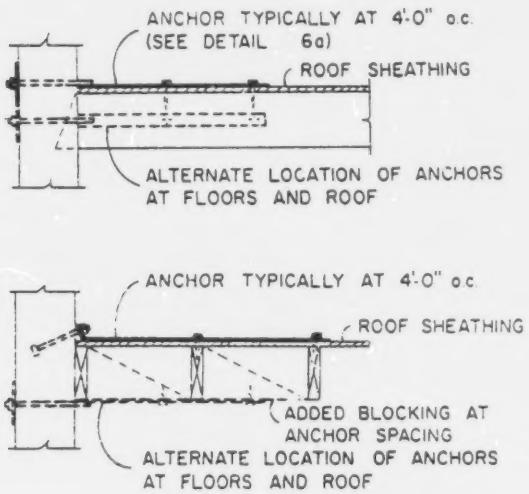


Figure 2: Concrete or masonry wall anchors to wood diaphragm.

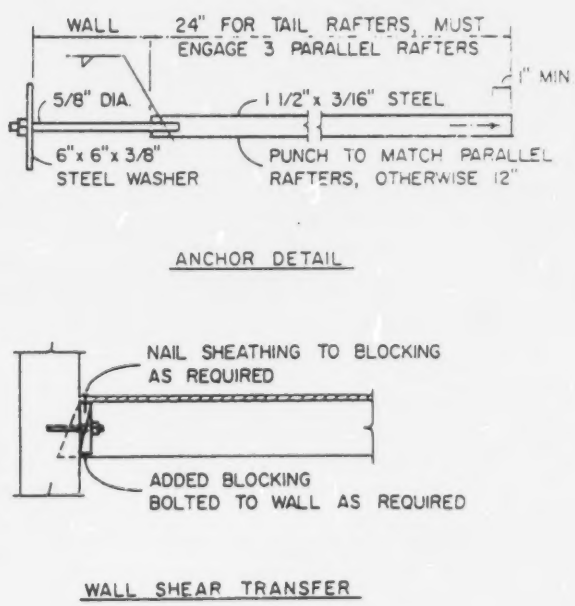


Figure 3: Strap anchor and blocking details.

3.1.2. Composite Floor-to-Wall Connections: Concrete topping on the existing floor are constructed as illustrated in **Figures 20, 21, 25, 26, 27, 28, 29.**

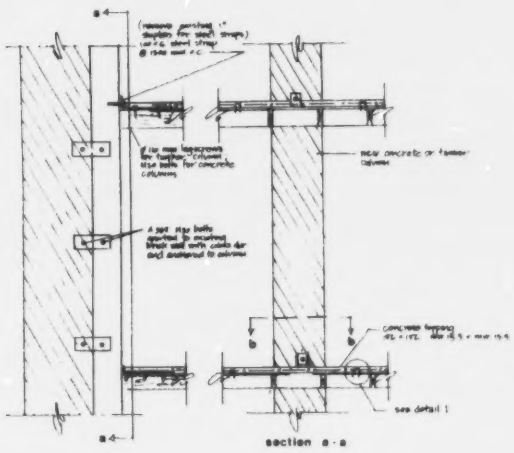


Figure 20

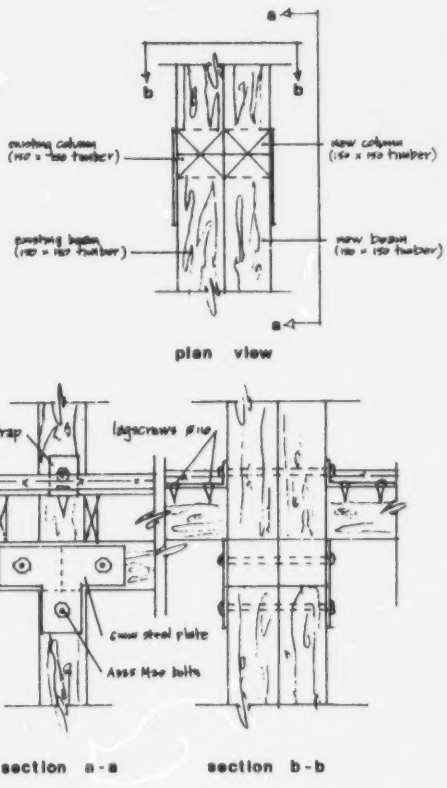


Figure 21

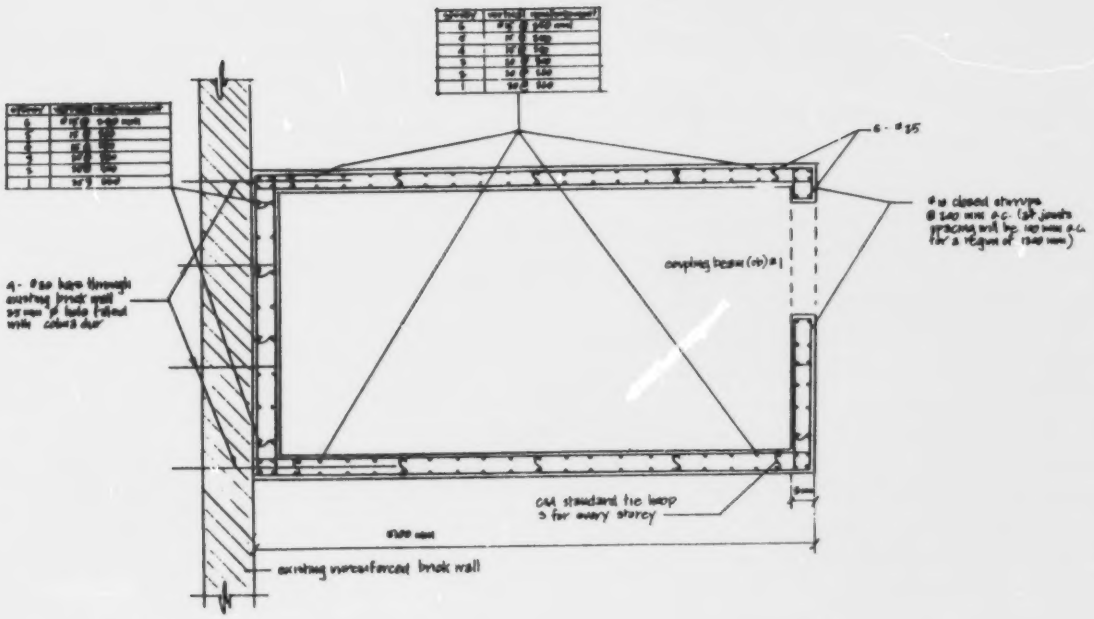

4 - #20 bars through existing brick wall 20 mm ø holes filled with cement slurry
6 - #25
#10 closed stirrups @ 150 mm o.c. (at joints spacing will be 100 mm o.c. for a region of 1500 mm)
coupling beam (typ) #1
CM standard tie loop 3 for every storey
existing unreinforced brick wall

Figure 25: Core reinforcement.

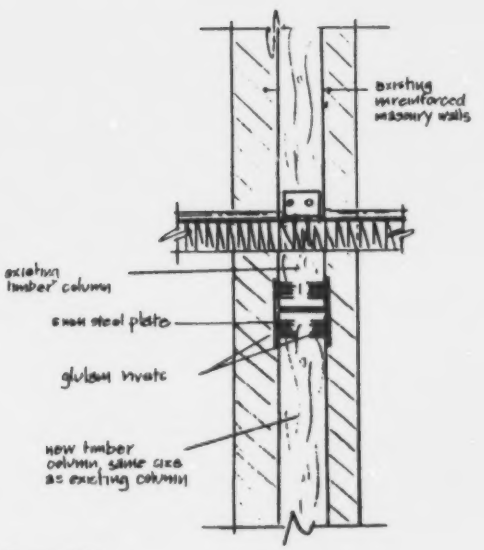

existing unreinforced masonry walls
existing timber column
6 mm steel plate
glulam rivets
new timber column, same size as existing column

Figure 26

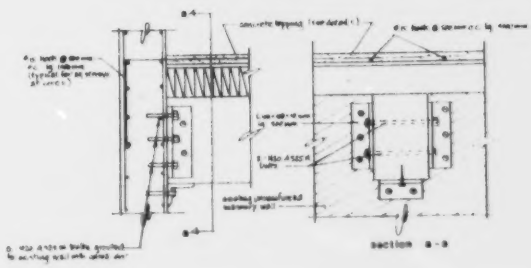


Figure 27

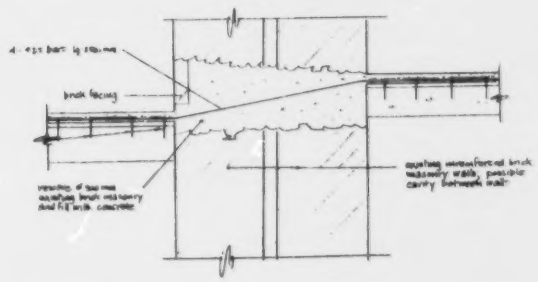
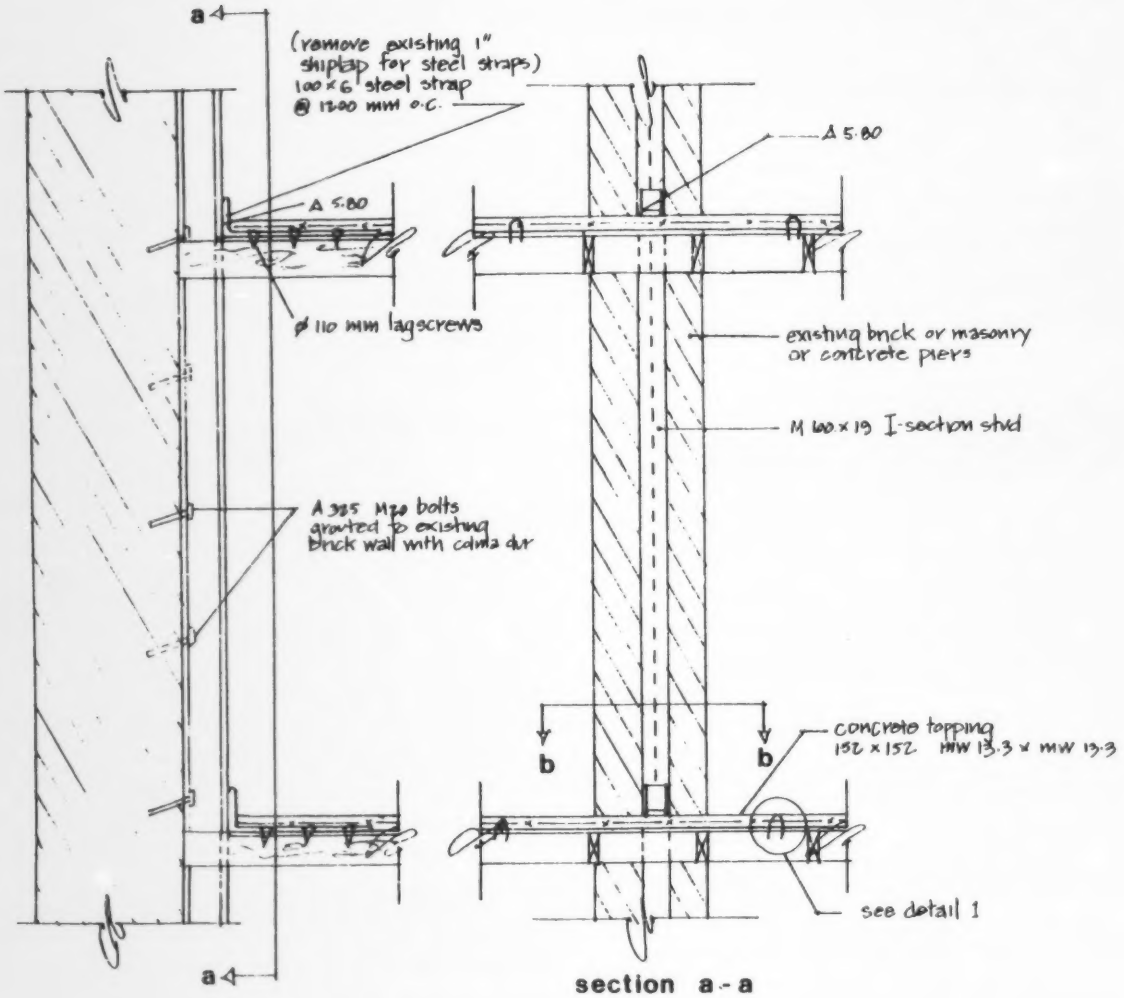


Figure 28


a
(remove existing 1" shiplap for steel straps)
100 x 6 steel strap @ 1200 mm o.c.
A 5.80
A 5.80
ø 110 mm lagscrews
existing brick or masonry or concrete piers
M 460 x 19 I-section stud
A 325 M20 bolts grouted to existing brick wall with calma dur
b
b
concrete topping 152 x 152 MW 13.3 x MW 13.3
see detail 1
a
section a-a

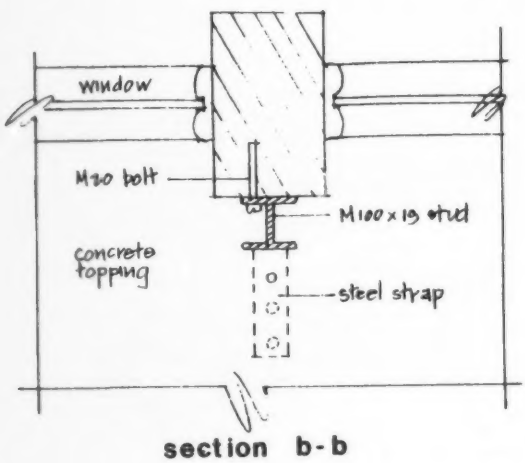

window
M20 bolt
M100 x 19 stud
concrete topping
steel strap
section b-b

Figure 29

3.2. Added Earthquake-resistant Systems

Generally in the longitudinal and transverse directions earthquake-resistant systems are necessary, such as:

3.2.1. Steel Rigid Frames: This method is used for Sub Block 1: Steel frames are placed in the center of the Sub Block in the east-west direction with rigid floor diaphragms (concrete topping or steel layers on the existing timber floor) transfering the lateral loads to these frames. In the north-south direction the unreinforced masonry walls are braced to resist the lateral loads (see wall strengthening details in **Figures 19, 20, 25, 26**).

3.2.2. Steel Framing Running through the Entire Block: The advantage of this layout is to use the existing timber floor as a flexible diaphragm with the proper details as indicated in clause 3.1.1. (see **Figures 2, 3**) since each frame is considered to be a separate structural system. The lateral forces acting on the frame are a function of the tributary mass assigned to the frame; these forces are resisted by the frame (Reference 3). Individually, the buildings can still be tied together and considered as single units with this method, but the interior space or value of the buildings is not significantly improved.

3.2.3. Reinforced Concrete or Masonry Cores: A reinforced concrete or masonry core or several cores can be used to resist lateral loads. Rigid floor diaphragms are necessary (ie. wood floors should be strengthened as in clause 3.2.1.). This method of strengthening buildings that have poor seismic resistance was selected as the most appropriate method within the constraints of maintaining the building's architectural and historical value, and improving the potential economical value of the building. This method is discussed in more detail in Chapter 4.

3.2.4. Combined System: A combined system contains a reinforced concrete or masonry shaft and reinforced concrete or steel frames resisting together against lateral loads.

3.2.5. Removing the Existing Interior System: The Holland Block has a poor vertical load carrying system but is architecturally unique. The ultimate solution could be removing the existing interior elements and replacing a proper architectural and structural system. The cost of doing this is more than the above solutions but it ensures the preservation of an old and valuable building.

3.3. Wall Strengthening Methods

Since Gastown is in seismic zone (3), all the masonry walls should be reinforced masonry walls (Reference 4). The following wall strengthening details can be applied to the unreinforced masonry walls:

3.3.1. Placing Columns into the Walls: Reinforced concrete or steel columns can be placed into the interior walls to transfer the lateral loads coming from different floor levels to a avoid tensile stresses in the direction perpendicular to the walls. These columns are also effective in resisting the walls' own inertia forces in the direction perpendicular to the plane. With the external reinforcement and/or prestressing tendons these reinforced masonry walls become earthquake resistant elements in the longitudinal direction (north-south direction for specific block). **Figure 19** illustrates this scheme.

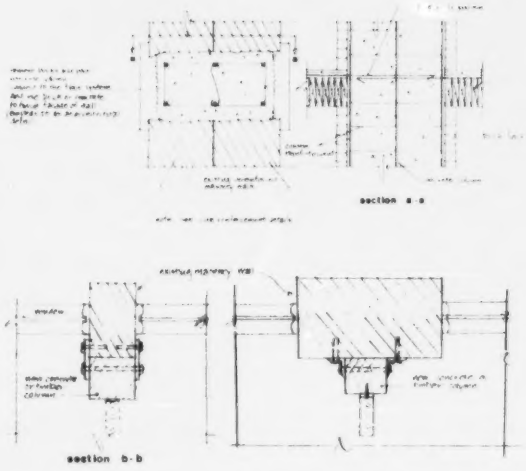


Figure 19

3.3.2. Reinforced Shotcrete: Application of a layer of shotcrete reinforced with vertical and horizontal bars is the recognized method for strengthening load bearing and non-structural masonry in North America (see **Figure 4**). But since maintaining the architectural and historical character of the buildings is important, the shotcrete application is not suitable as it covers the aesthetic character of the well maintained masonry brick walls.

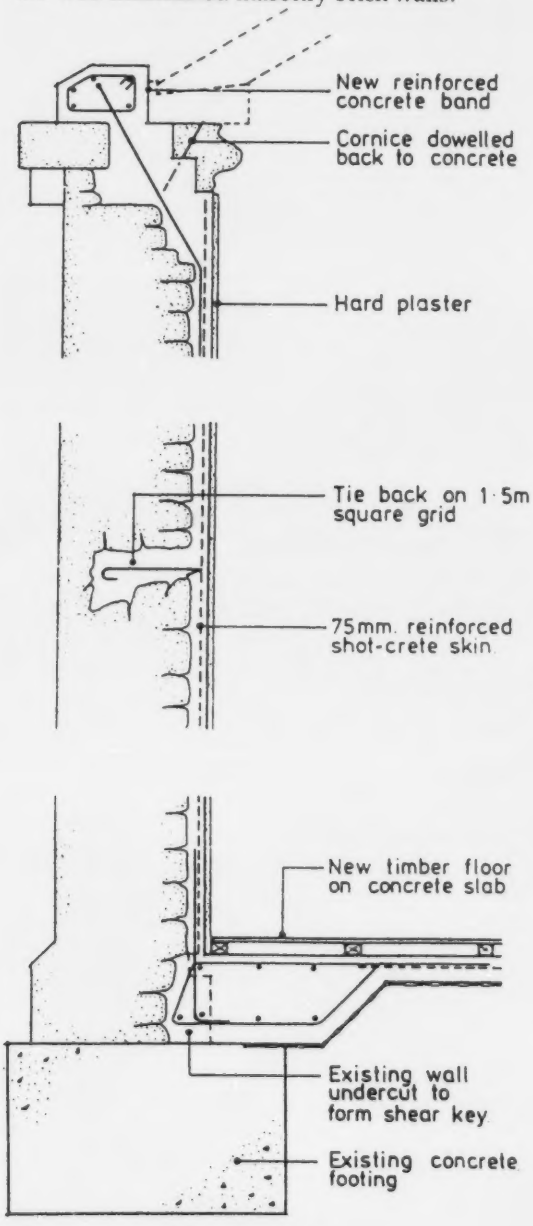

New reinforced concrete band
Cornice dowelled back to concrete
Hard plaster
Tie back on 1·5m square grid
75mm. reinforced shot-crete skin
New timber floor on concrete slab
Existing wall undercut to form shear key
Existing concrete footing

Figure 4: Wall strengthening details.

3.3.3. Surface Treatments: As with the application of shotcrete, surface treatments such as using reinforcing fabrics followed by a 1 in. to 2 in. layer of mortar, metal sheets plus a thin layer of mortar and "surewall" application are limited because of the reasons mentioned above.

3.3.4. Vertical and Horizontal Tendons: External reinforcing of the walls with vertical and horizontal tendons is a common method for strengthening unreinforced masonry walls. Prestressed or non-prestressed reinforcing bars mechanically attached to the existing masonry walls greatly improve their lateral load resistance and ductility (see **Figure 5**).

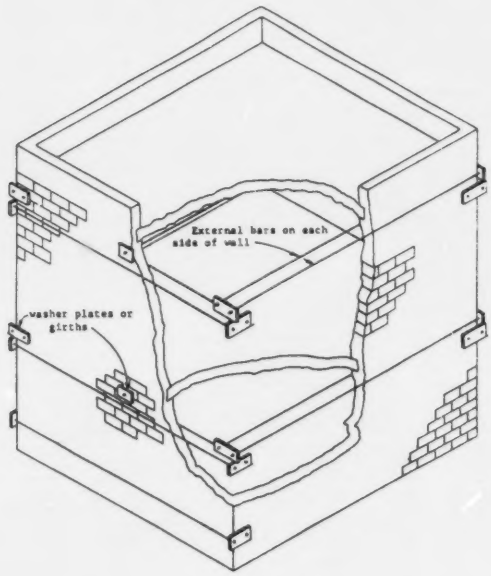


Figure 5: External reinforcement and/or prestressing tendons used to connect transverse walls and walls-to-floors.

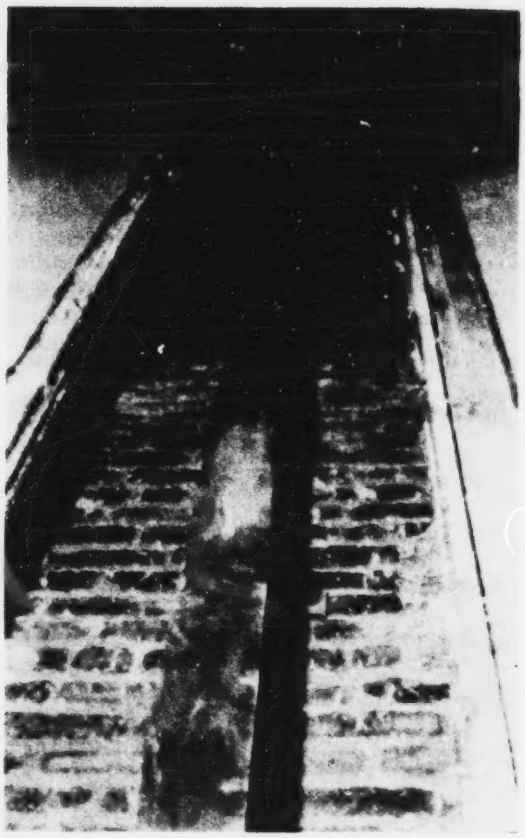


Figure 6: Ground floor of Hotel Oakland, which high storey height required steel wide flange beam spanning between floors with epoxy bolts in the exterior brick walls attached for wall forces perpendicular to the wall.

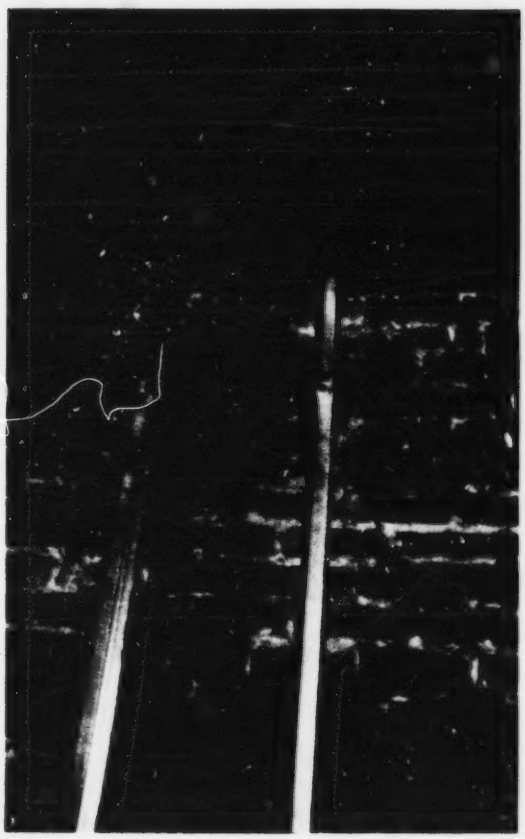


Figure 7: Bracing of unreinforced brick on typical floor of Hotel Oakland restoration. Epoxy bolt in brick connected to heavy duty furring studs which spanned between floors.

Figure 8: Timber framing showing veneer ties and fixing to top band.

Figure 9: Anchorage of studs at wall ends and openings.

3.3.5. External Reinforcing with Vertical Studs: Timber, concrete or steel studs can be the solution to prevent tensile stresses in the unreinforced masonry walls in the direction perpendicular to the plane. These studs are grouted to the walls by bolts. The addition of horizontal tendons to the above scheme makes the walls earthquake resistant elements in the direction of their planes (see **Figures 20, 23, 25, 26, 29**).

3.3.6. Strengthening of Corners and Intersections: At corners and some wall intersections, long steel flats are provided at each side of the wall, bent around the corner and bolted together through the wall to improve continuity.

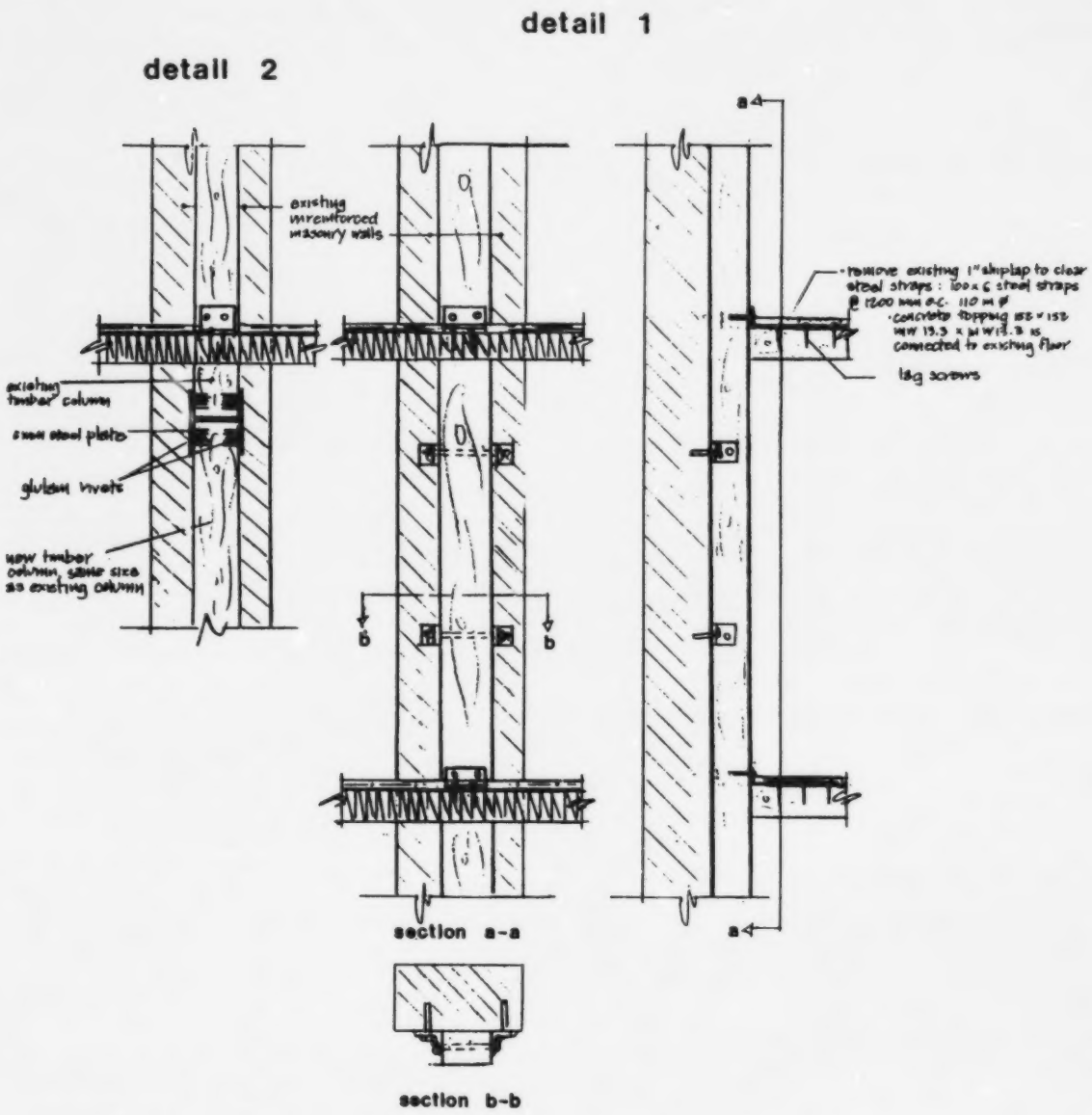

detail 1
detail 2
existing unreinforced masonry walls
existing timber column
new steel plate
glulam rivets
new timber column, same size as existing column
remove existing 1" shiplap to clear steel straps : 100 x 6 steel straps @ 1200 mm o.c. 110 mm ø
concrete topping 125 x 152 mw 13.3 x 14 W1.7 as connected to existing floor
lag screws
a
a
b
b
section a-a
section b-b

Figure 23: Wall strengthening details.

3.4 Anchoring the Existing Parapets

The existing parapets are potentially hazardous because they are cantilevered unreinforced masonry walls which commonly fail during earthquakes. **Figures 11, 12** show typical anchorage for parapets and cornices.

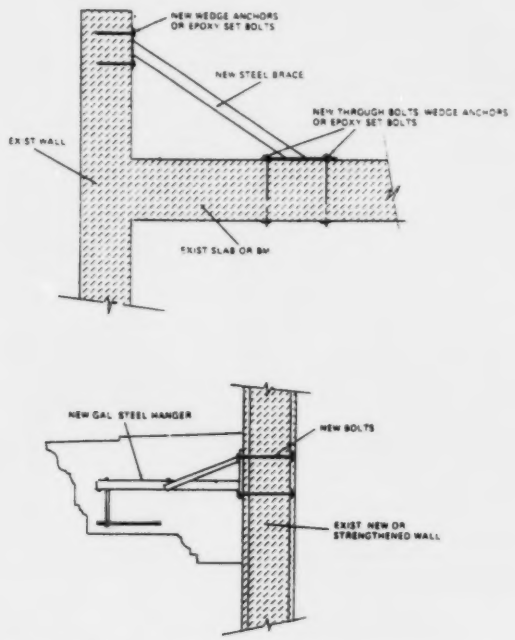

NEW WEDGE ANCHORS OR EPOXY SET BOLTS
NEW STEEL BRACE
NEW THROUGH BOLTS WEDGE ANCHORS OR EPOXY SET BOLTS
EXIST WALL
EXIST SLAB OR BM
NEW GAL STEEL HANGER
NEW BOLTS
EXIST. NEW OR STRENGTHENED WALL

Figure 11: Typical anchorage for parapets and cornices.

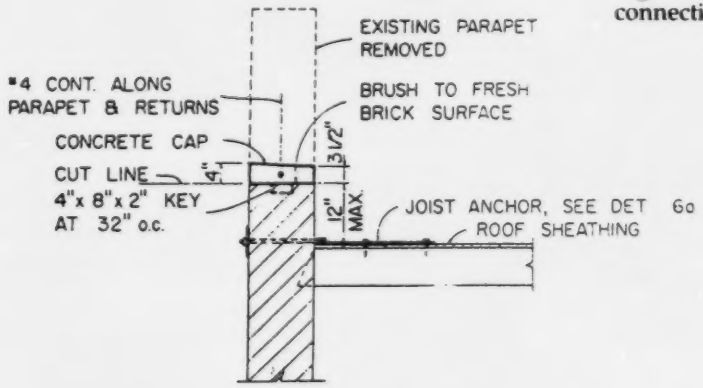


Figure 12: Typical parapet correction detail.

3.5. Bracing of Poor Vertical Load-resisting Systems

Some buildings (for instance the Edward Hotel) have poor vertical load-resisting systems and also some missing columns and beams. They should be braced and/or replaced by additional structural elements.

3.6. Connections between Cast Iron Columns and Steel Lintels

The cast iron columns on the ground floors of some of the buildings should be connected to the steel lintels (see **Figure 13**).

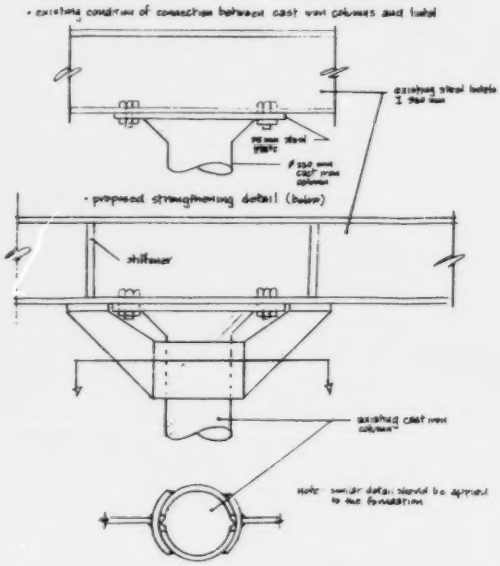


Figure 13: Strengthening details for connections.

3.7. Connections of Heavy Timber Frames

Generally, the buildings with more than five floors, have heavy timber frames to resist the vertical loads. Their connections can have moment resisting capacity which increase the earthquake resistance of the structure (a detail which can be applied, illustrates a typical braced connection in **Figure 14**).

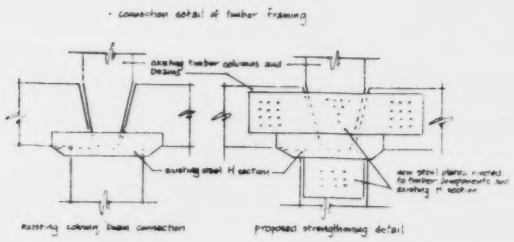


Figure 14: Connection detail of timber framing.

3.8. Cracks on Timber Components

Numerous cracks have been observed on the timber columns and beams. They should be fixed by steel straps or another proper detail.

3.9. Cracks on Masonry Walls

Cracked masonry walls typically are repaired by filling the cracks with a masonry grout or an epoxy cement. The masonry grout combines portland cement, lime, and water into a high slump mixture.

3.10. Bracing of Openings

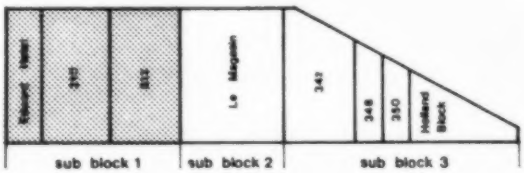
Where openings are essential in structurally important positions, a four sided frame in reinforced concrete or structural steel is placed into the opening. This is designed to replace the strength of brick work removed, based on 0.07 MPa shear stress (Reference 5).

4. Consolidated Design of Sub Blocks

The comparative cost of seismic upgrading for these buildings individually or as a group, is determined by several factors rather than by the costs of structural improvements alone. Requirements of fire safety, exiting, architectural improvements, etc. are also involved. With a consolidated design, the eight buildings in the study block are essentially treated as three buildings. Limited by the architectural constraints to preserve these buildings, Sub Block 1 and Sub Block 3 were designed using reinforced concrete cores as major structural elements to resist seismic forces. Each of these sub blocks has one entry lobby and a central service core consisting of elevators, fire stairs, washrooms and ducts. As a result of condensing these into one building to serve three or four, the construction costs can be significantly reduced and the net usable area of the buildings increased up to 7% more than the figures calculated for individual upgrading.

4.1. Design of Sub Block 1

Sub Block 1 consists of the three buildings on the east side of the study block: the Edward Hotel, and 310 and 322 Water Street.



sub block 1 (includes the Edward Hotel; 310 and 322 Water Street) gross floor area: 69,880 sq.ft.	individual upgrading	rentable 57,377	not usable 51,950
	consolidated design	61,154	56,743
sub block 3 (includes the Holland Block; 347, 348, and 350 Water Street) gross floor area: 47,160 sq.ft.	individual upgrading	rentable 38,341	not usable 35,501
	consolidated design	42,012	38,990

4.1.1. Structural System Layout: Two structural systems have been analysed for Sub Block 1:

4.1.1.1. First Proposed Structural System: The first proposed strengthening scheme consists of seven steel rigid frames which run through the Central Building (310 Water Street) in the east-west direction. A new 60 mm. concrete topping (reinforcement: 152x152 MW. 13.3x13.3) is anchored to the existing timber floor and to the frames and walls. On the ground floor level the approximate sections (W310x179 for the columns and W310x283 for the beams) resisted to 75% of the seismic loading.

Steel columns are placed into the exterior unreinforced masonry walls in the following manner:

Remove vertical sections in the brick walls to maintain an irregular, saw-tooth surface in the remaining wall, insert a steel column, then connect the floor system to these columns and cast in concrete made with crushed brick as aggregate.

These columns will take the lateral forces from adjacent buildings and the out of plane forces of the walls and will tie the buildings together in the Sub Block.

With the horizontal tendons at each floor level these walls become earthquake resistant elements in the north-south direction (see **Figure 5**).

All the exterior unreinforced masonry walls are anchored to the floors and vertical steel studs are added to prevent their failure in the direction of perpendicular of their planes (see **Figures 20, 25, 26**).

4.1.1.2. Second Proposed Structural System: The second proposed strengthening scheme introduces a reinforced concrete central core which consists of one elevator shaft, two staircases, washrooms and ducts. A new concrete topping is added to the existing floor system and connected to the walls and core as mentioned above (see **Figure 15**).

The core was reinforced against 100% of the earthquake loading (see **Figures 16, 17, 18, 19**).

Since there are considerable level differences between the buildings, reinforced concrete columns are placed into the interior unreinforced masonry walls to transfer the lateral loads from one floor level to another in the adjacent building.

Construction of these columns into the walls can be done as follows:

Remove vertical sections in the brick walls, maintain an irregular saw-tooth surface in the remaining brick wall, place reinforcement and connect it with the floor reinforcement, place horizontal tendons at every floor level, then cast in concrete (see **Figure 19**).

The above reinforced walls are earthquake resistant members in the north-south direction.

As well, these columns tie the buildings together in the Sub Block.

All the exterior unreinforced masonry walls are anchored to the floors and vertical heavy timber and/or reinforced concrete columns are added to prevent their failure in the direction perpendicular to their planes.

The timber framing of the Edward Hotel's structural system was removed and replaced with new heavy timber framing because of the reasons mentioned in clause 3.5.

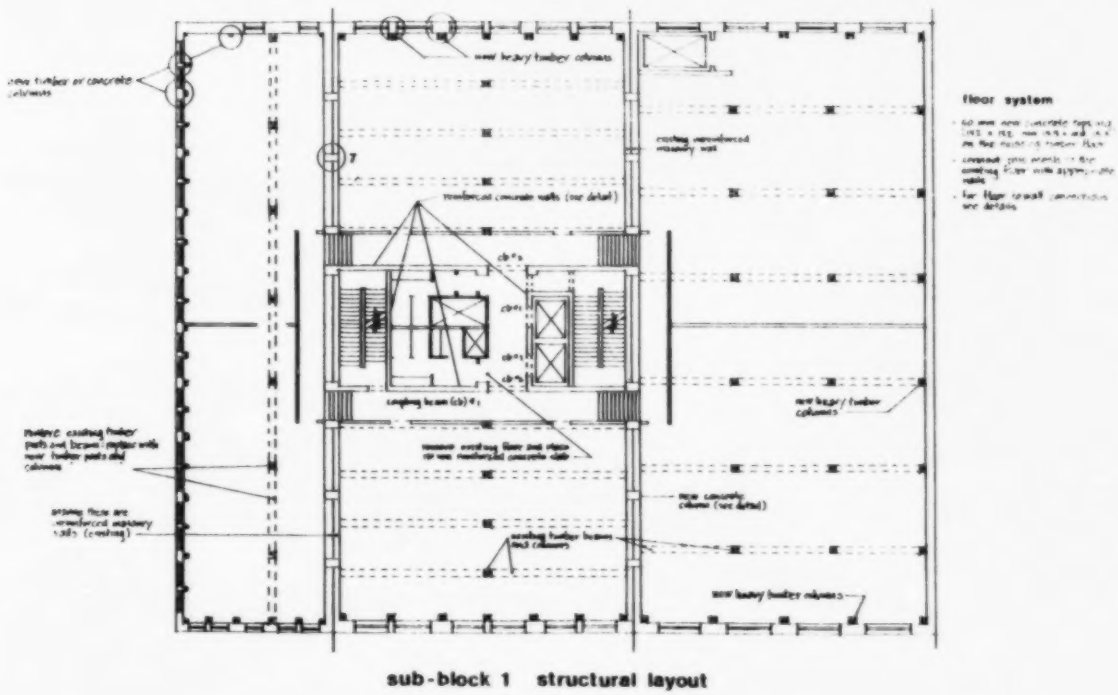


Figure 15: Sub Block 1 structural layout.

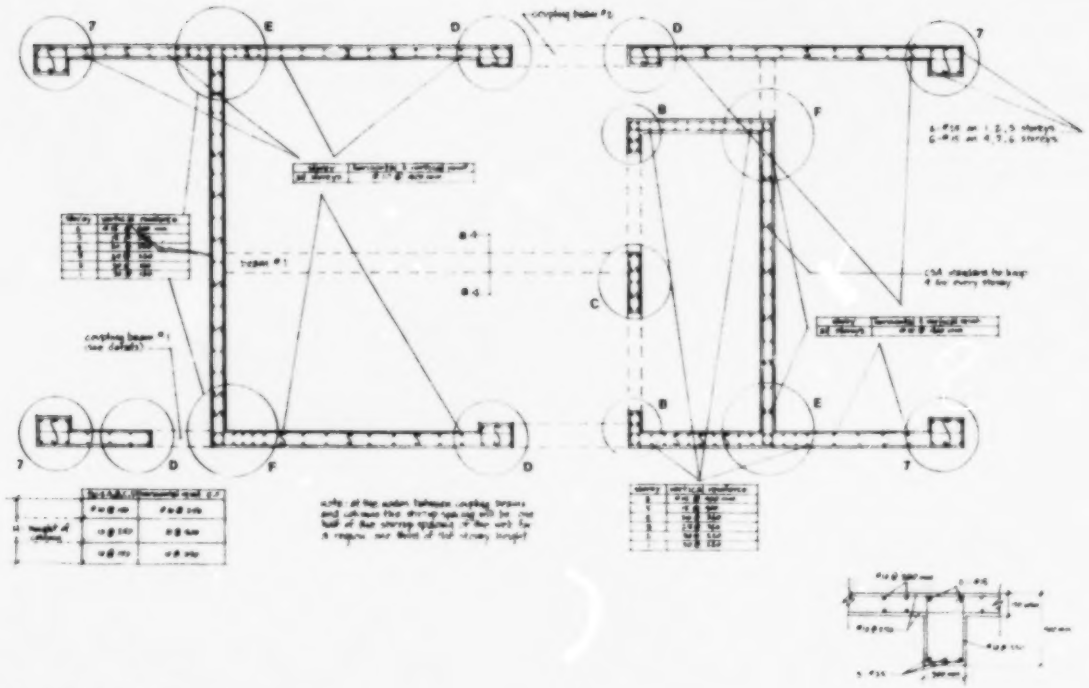


Figure 16: Core reinforcement.

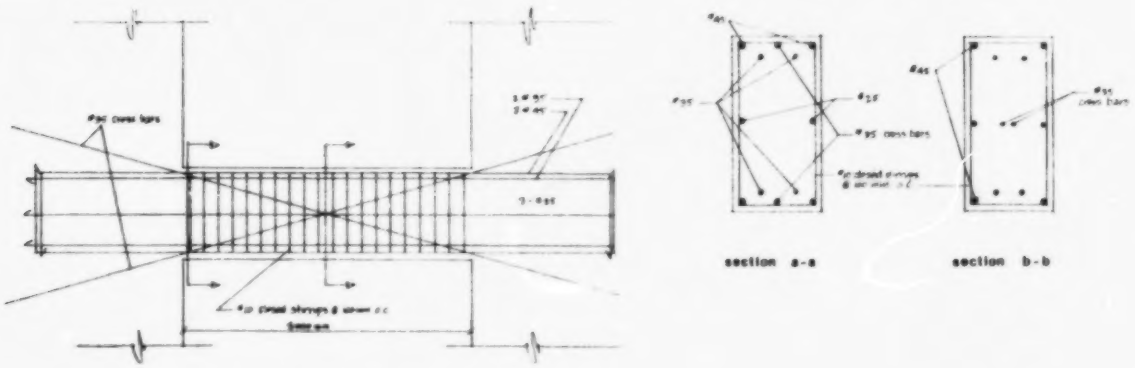


Figure 17: Reinforcement details: coupling beam 1.

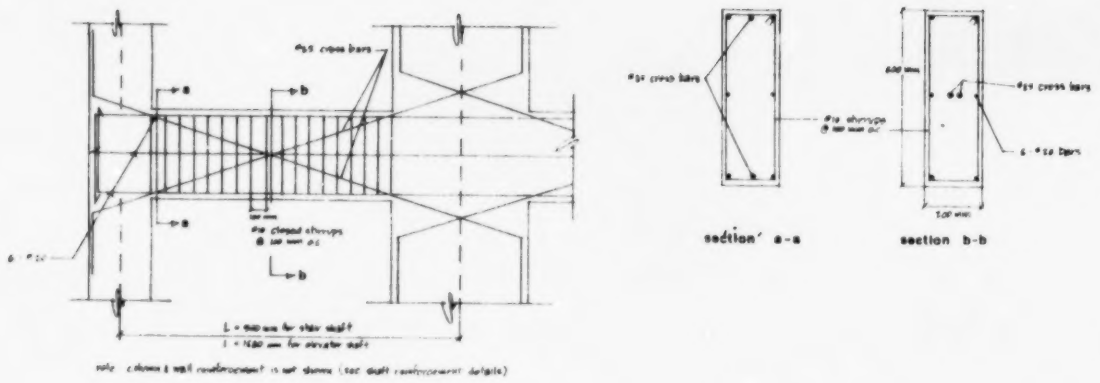


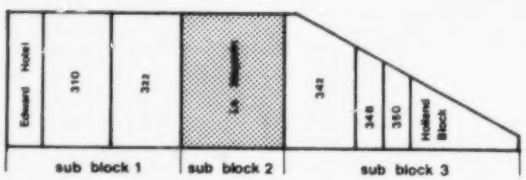
Figure 18: Reinforcement details: coupling beam 2.

4.2. Design of Sub Block 2

Sub Block 2 consists of Le Magasin as a single unit. Since this building is only a three storey building and has heavy timber framing and floor system, the following structural retrofitting is sufficient to upgrade the building:

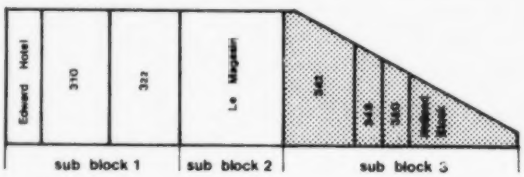
The missing columns and beams are replaced to obtain continuity of the structural system and provide better connection between columns and beams with the use of steel plates and glulam rivets (see **Figure 14**).

The floor system is connected to the vertical structural elements to transfer the lateral loads.



4.3. Design of Sub Block 3

Sub Block 3 consists of the four buildings on the west side of the study block: 342, 348 and 350 Water Street, and the Holland Block.



4.3.1. The Proposed Structural System: The proposed strengthening scheme consists of three reinforced concrete typical staircases and one elevator shaft (see **Figures 22, 23, 24**). A new concrete topping (60 mm. thick with welded wire mesh same as the above strengthening schemes) is placed on the existing timber floor. This composite floor system is well connected to the brick walls and shafts (see **Figures 25, 26, 27**). These reinforced concrete shafts are well placed so that even with the triangular shape of the Sub Block, the stiffness centre of the Sub Block coincides with the centre upon which horizontal resultant forces are acting. Therefore, torsion effects do not occur.

The buildings in the Sub Block are tied together by the reinforced concrete horizontal elements since there are no or very little level differences between the adjacent buildings (see **Figure 28**). These elements are constructed by removing a hole (approximate diameter is 30 cm.) in the brick walls, maintaining an irregular saw-tooth surface in the remaining brick wall, placing horizontal reinforcement from one floor to another, and casting in concrete simultaneously with the concrete topping onto the floor system.

All the unreinforced brick or stone masonry walls are anchored to the floors and heavy timber and/or reinforced concrete columns are added to prevent their failure in the direction perpendicular to the plane.

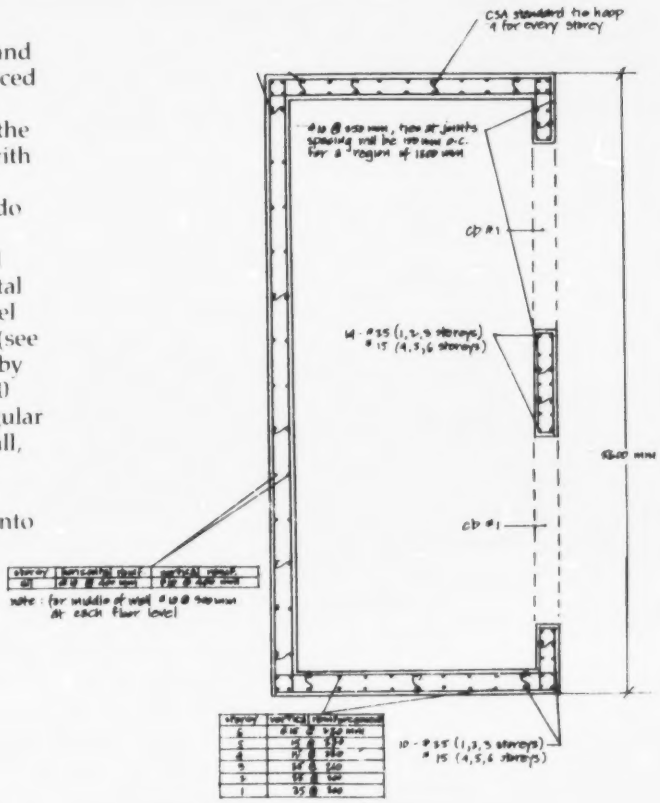


Figure 24: Core reinforcement.

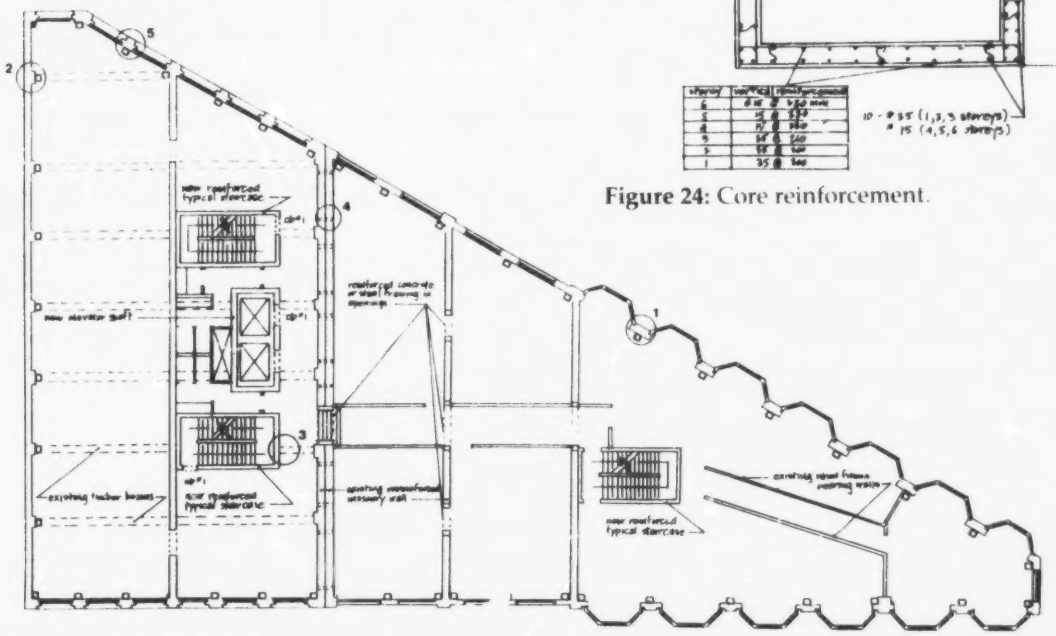


Figure 22: Sub Block 3 structural layout.

Conclusion

Heritage buildings present unique problems in how they should be seismically upgraded because of the old materials and techniques used to construct them, and the desire to preserve features of the buildings which have some architectural or historical significance. This study recommends several methods that can be applied to these buildings, and other buildings of this type and nature, by adding new structural elements and/or strengthening the existing structural systems to increase the buildings' seismic resistance. The general structural requirements to achieve this are:

1. All the unreinforced masonry walls must be strengthened to provide lateral stability.

2. The walls must be connected to the floor systems.

3. General retrofitting must be provided in each building; such as replacing columns and beams where they are missing and properly connecting beams to columns to improve their moment resisting capacity.

4. An earthquake resistant system must be provided in the longitudinal and transverse directions of the building(s); such as adding reinforced masonry or concrete shaft(s) or rigid frames for the consolidated design proposed.

5. Buildings which have poor vertical load resisting systems must be braced.

6. Where necessary, openings in the walls (ie. windows and doors) should be braced to replace the strength of masonry removed.

7. Existing parapets and cornices should be properly anchored to the building to prevent their failure in the event of an earthquake.

The methods for seismic upgrading proposed in this study use heavy timber, brick, steel and concrete structural elements in a compatible manner with the existing materials of the building. Precautions were taken to restrict the use of structural elements on the facade of the buildings which would significantly alter their general physical character. The comparative costs of these methods as applied on an individual basis or to a group of buildings can be determined by a qualified professional from the information provided for each system.

Structurally a consolidated approach for seismic upgrading is favoured over individual upgrading since the buildings can act together as a unified group and effectively increase their ability to resist seismic forces. This approach also has the economic advantages of reduced construction costs and potentially greater return generated by an increase in rentable space. One major problem associated with a consolidated design, though, is the legal ramification of building ownership. Generally, it requires the individual building owners to agree on this approach and work cooperatively to fulfill its potential or that the proposed consolidated design be developed by a new single owner.

Although time constraints prevented a similar analysis of a study block in Chinatown as originally intended, the concept of a consolidated engineering design for seismic upgrading should be tested in this area in order to compare results. Hopefully, the information and research gathered over the past three months will be useful for the seismic upgrading of other heritage buildings.

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